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1

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TITLE WEAR AND FRICTION OF THIN FILM HIGH TEMPERATURE OXIDE SUPERCONDUCTORS

AUTHOR(S) Michael Nastasi, MST-7
Juha-Pekka Hirvonen, MST-7
Risto O. Toivanen, Helsinki Univ. of Technology

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

WEAR AND FRICTION OF THIN FILM HIGH TEMPERATURE OXIDE SUPERCONDUCTORS

M. Nastasi and J-P. Hirvonen
Materials Science and Technology Division
Los Alamos National Laboratory, Los Alamos, NM 87545

and

R.O. Toivanen
Helsinki University of Technology, Espoo, Finland

Summary

We have examined the sliding properties of a Nd-Fe-B magnet against a thin film $YBa_2Cu_3O_7$ superconductor. Pin-on-disk experiments were performed at room temperature and in normal air using a 10 mm magnetic Nd-Fe-B ball loaded to 31.22 g and a sliding speed of approximately 0.57 cm/sec. Such condition produced a steady state friction coefficient of 1.1 ± 0.3. Wear rate measurements indicated that Nd-Fe-B will wear $YBa_2Cu_3O_7$ at a rate 1.3×10^{-14} m^3/m and that the Nd-Fe-B/$YBa_2Cu_3O_7$ sliding system possess a wear coefficient of 4.2×10^{-14} m^3/Nm. These unusually high values appear to be the result of both abrasive and adhesive wear. Adhesion between the sliding surfaces is most probably enhanced by the oxygen reactivity of the pin material and the high oxygen content in the superconductor.

Introduction

The recent discovery of high temperature oxide superconductors opens several design possibilities for low friction bearing/race assemblies which would utilize magnetic bearings and levitation. However, in the event of accidental warm-up, contact between the superconducting race and the magnetic bearing would occur and knowledge of their friction and wear properties is desirable. In the present work we have examined the sliding properties of a Nd-Fe-B magnet against a $YBa_2Cu_3O_7$ thin film coating.

Experimental

Thin films of $YBa_2Cu_3O_7$ on non-oriented $SrTiO_3$ substrates were fabricated by the coevaporation of Y , BaF_2, and Cu in a vacuum of 5×10^{-8} torr. The deposition rate of each component was adjusted to ensure a Y:Ba:Cu ratio of 1:2:3. Following the evaporation the film/substrate couple was annealed for 1 hr at 750 ^{o}C in flowing dry oxygen followed by 1 hr at 850 ^{o}C in flowing wet oxygen and finally slow cooled in dry oxygen. The superconducting quality of the film was determined by four-point resistivity measurements, Fig. 1, which showed the film to posses a superconducting transition temperature of 83 K. Profilometer measurements gave a nominal film thickness of 3500 Å while high energy alpha particle backscattering analysis [1] gave an average composition of $Y_{1.1}Ba_{2.1}Cu_{3.0}O_{7.0}$.

The superconductors sliding counter part in wear and friction measurements was a 10 mm Nd-Fe-B magnetic ball. The rare-earth magnetic material, which was manufactured by sintering 3.4 μm powders at 1070 ^{o}C for 1hr followed by 650 ^{o}C for 1 hr, possessed a nominal composition in wt % of 33.1 Nd, 1.2 B, and 65.7 Fe. Analysis indicated the presence of three phases $Nd_2Fe_{14}B$, $NdFe_4B_4$, and Nd, a density of 7.4 g/cm^3, a Vickers hardness number of 600, a remanent induction of 1.29 T, a coercive force of 740-780 kA/m, and a maximum energy product of 309 kJ/m^3.

All wear and friction experiments were performed at room temperature, using a pin-on-disk apparatus operating in normal air at a sliding speed of approximately 5.7 mm/sec. A 10 mm Nd-Fe-B magnet ball, loaded to 31.22 g, was employed as the pin.
All magnetic materials were removed from the vicinity of the pin and replaced by aluminum for the duration of these experiments. The Nd-Fe-B pin was found to be relatively reactive in room air, building up a visible oxide in several days. As a result the pin was polished with diamond spray down to a grade of 0.3 μm immediately prior to each test. Wear analysis was carried out using scanning electron

microscopy (SEM), energy dispersive spectroscopy (EDS), and profilometer measurements.

Results and Discussion

Friction coefficient data as function of wear cycles is presented in Fig. 2. This data shows that the $YBa_2Cu_3O_7$/Nd-Fe-B sliding couple is clearly not a low friction system. Within a very short period (~ 300 cycles) the coefficient of friction increased from an initial value of approximately 0.3 to a steady state value of 1.1 ± 0.3 which was maintained out to 2500 cycles. The friction behavior was characterized by strong stick-slip type oscillation through the steady state regime. These oscillation give rise to the wide data band present in Fig.2. The mean steady state value of this system is quite high, especially when compared to other engineering systems such as a hardened chromium steel pin on 304 stainless steel with a friction coefficient of 0.9 [2] or a steel pin on Si_3N_4 with a friction coefficient of 0.68 [3].

The wear character of the $YBa_2Cu_3O_7$ film was examined using both SEM and EDS. Wear examination of the Nd-Fe-B pin was performed using optical microscopy which showed the occurrence of heavy wear on this component. Micrographs of typical wear tracks in the oxide superconductor at 200, 700, and 2500 cycles are presented in Fig.3. These data suggest that wear of the superconductor occurs primarily through an abrasive mechanism. However, the observation of excessive pin wear together with the high friction and stick-slip behavior exhibited in Fig. 2 suggest strong chemical interactions between the sliding surfaces and the occurrence of adhesive wear. This is consistent with the Nd-Fe-B materials observed affinity for oxygen and the high oxygen content in the thin film superconductor (53 at%). Most probably both an abrasive and an adhesive mechanism coexist, with wear debris making the abrasive mechanism three-body in nature.

Corresponding EDS data from an unworn portion of the film and from the wear tack following 2500 cycles is presented in Fig 4. These data were taken following an ultra-sonic cleaning in methanol to remove all lose wear debris. Due to signal overlap between both Sr and Ti x-rays in the energy interval of 1.58 to 2.08 keV and between Ti and Ba x-rays in the energy interval of 4.47 to 4.90 keV, a qualitative measures of film wear-through was made using the Cu K_a 8 keV. The Cu signal was observed in the wear track following 700 cycles indicating that some superconducting film is still present. However, as Fig. 4 indicates, neither of the Cu signals initially present at 0.8 and 8 keV Cu are observed following 2500 cycles indicating that wear through has. At no time did the EDS data suggest the presence of Fe or Nd in the wear track region.

Both the wear rate and wear coefficient of the oxide high temperature superconductor were determined from profilometer measurements of wear tracks. In Fig 5. the wear volume as a function of total sliding distance is presented. Similar to the friction data presented in Fig. 2, the wear volume shows a very short run-in period after which the steady state regime is reached. The steady state slope indicates that Nd-Fe-B will wear $YBa_2Cu_3O_7$ at a rate 1 3×10^{-14} m^3/m and that the Nd-Fe-B/$YBa_2Cu_3O_7$ sliding system possess a wear coefficient of 4.2×10^{-14} m^3/Nm. This wear coefficient is 4 times larger than observed for a steel pin on Si_3N_4 [ref].

These experiments have shown that the Nd-Fe-B-magnet/ $YBa_2Cu_3O_7$-superconductor sliding system does not possess good tribological properties. This system possess an extremely high coefficient of friction, 1.1, and wears the oxide superconductor at a rate of 1.3×10^{-14} m^3/m. These unusually high values are most likely the result of both abrasive and adhesive wear. Adhesion between the sliding surfaces is most probably enhanced by the oxygen reactivity of the pin material and the high oxygen content in the superconductor. In any event, these data suggest that contact between these components should be minimized in any potential future application.

References

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Figures

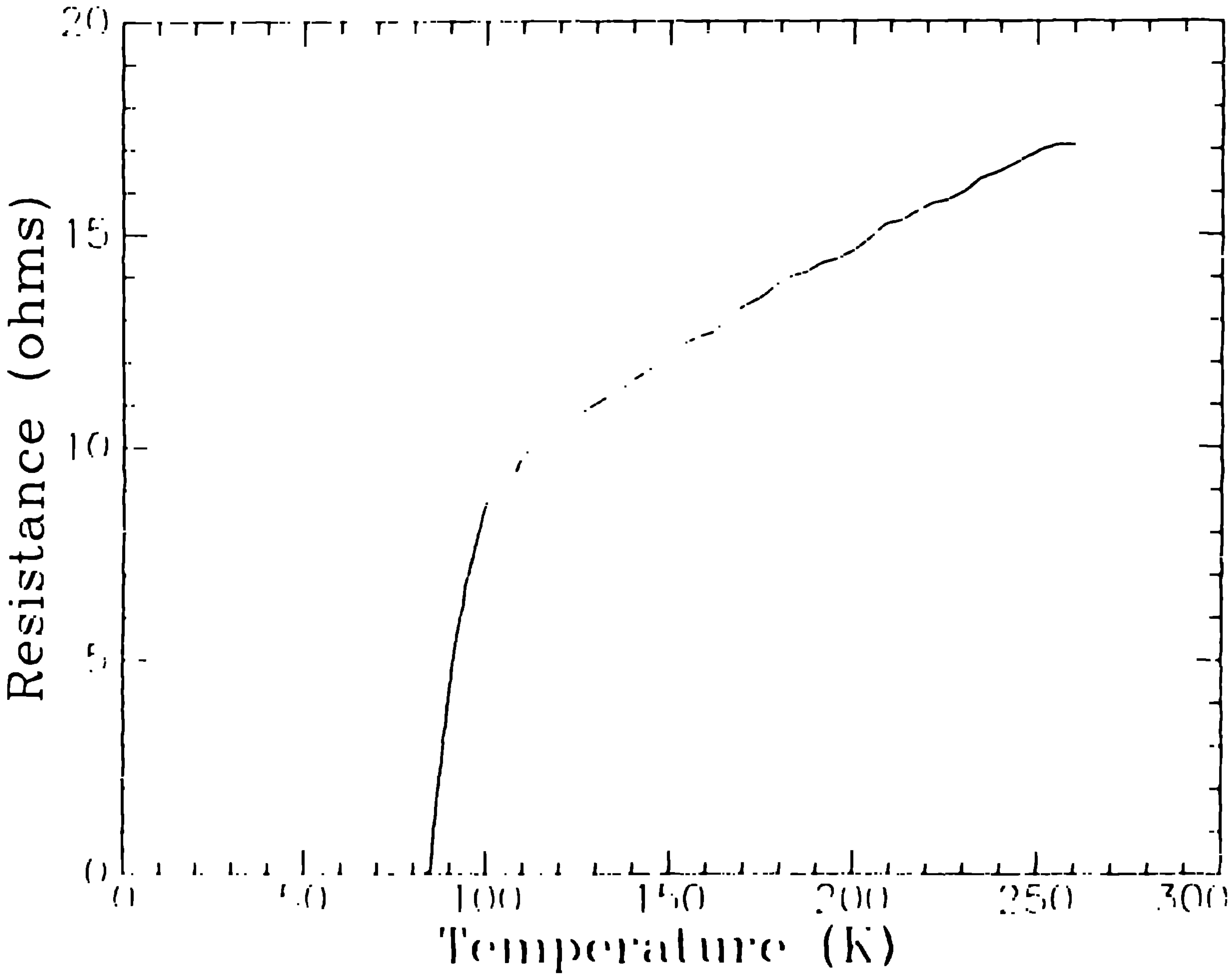
Fig. 1. Four-point resistance data from a 3500 Å $Y_{1.1}Ba_{2.1}Cu_{3.0}O_{7.0}$ superconducting film grown on a non-oriented $SrTiO_3$ substrate.

Fig. 2. Friction coefficient data as function of wear cycle for a Nd-Fe-B pin sliding against a $Y_{1.1}Ba_{2.1}Cu_3O_7$ film in room air at room temperature.

Fig. 3. Micrographs of typical wear tracks in the oxide superconductor at 200, 700, and 2500 cycles .

Fig. 4. EDS data from an unworn portion of the film and from the wear tack following 2500 cycles. The absence of the 8 keV Cu signal at 2500 cycles indicates wear-through has occurred.

Fig 5. The $YBa_2Cu_3O_7$ wear volume as a function of total sliding distance. The steady state slope indicates that Nd-Fe-B will wear $YBa_2Cu_3O_7$ at a rate $1.3x10^{-14}$ m^3/m.



20
15
10
5
0
Resistance (ohms)
0
50
100
150
200
250
300
Temperature (K)

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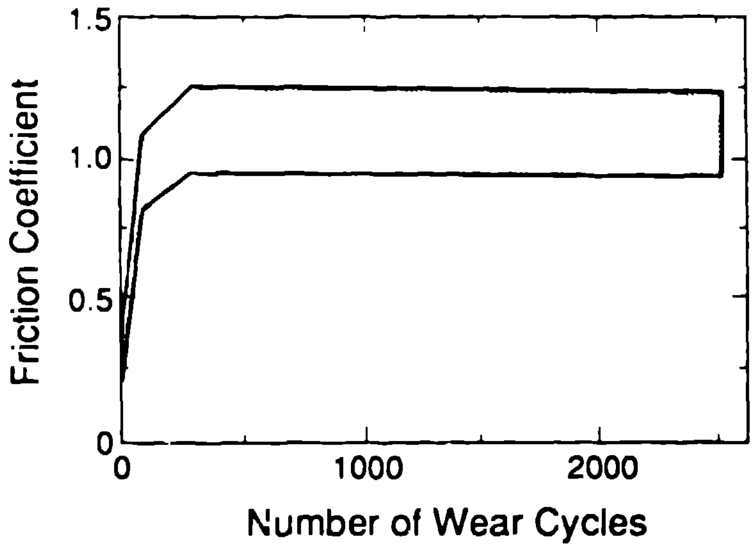

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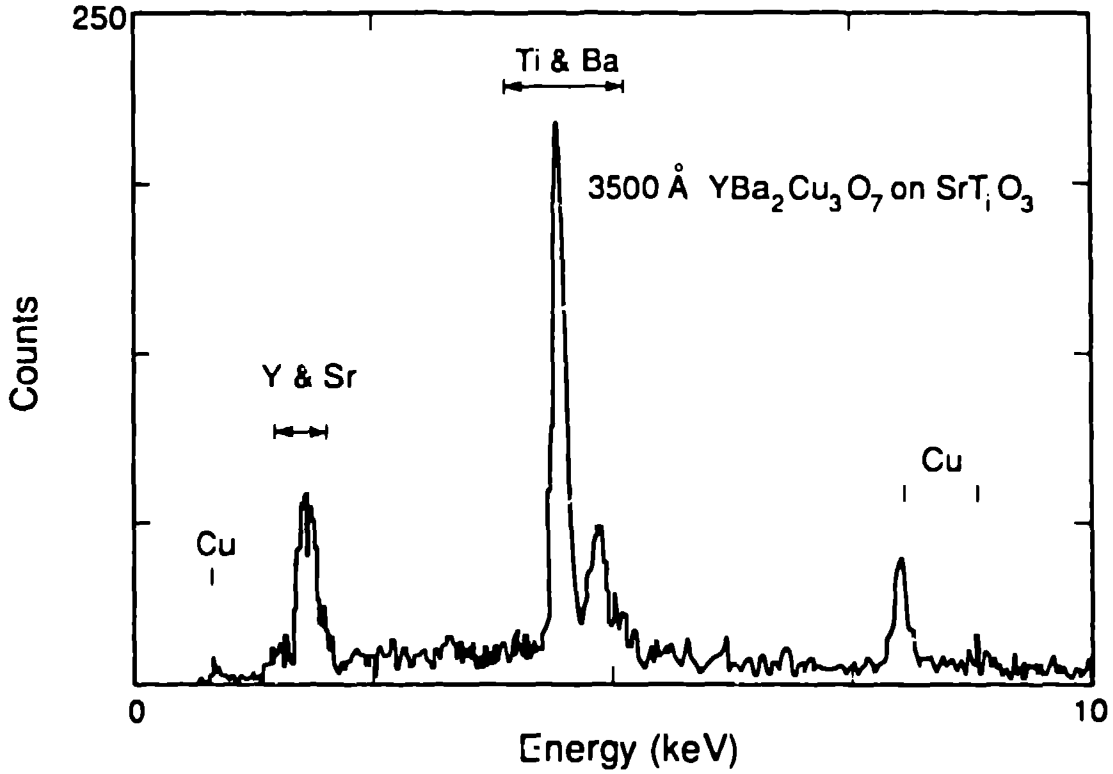

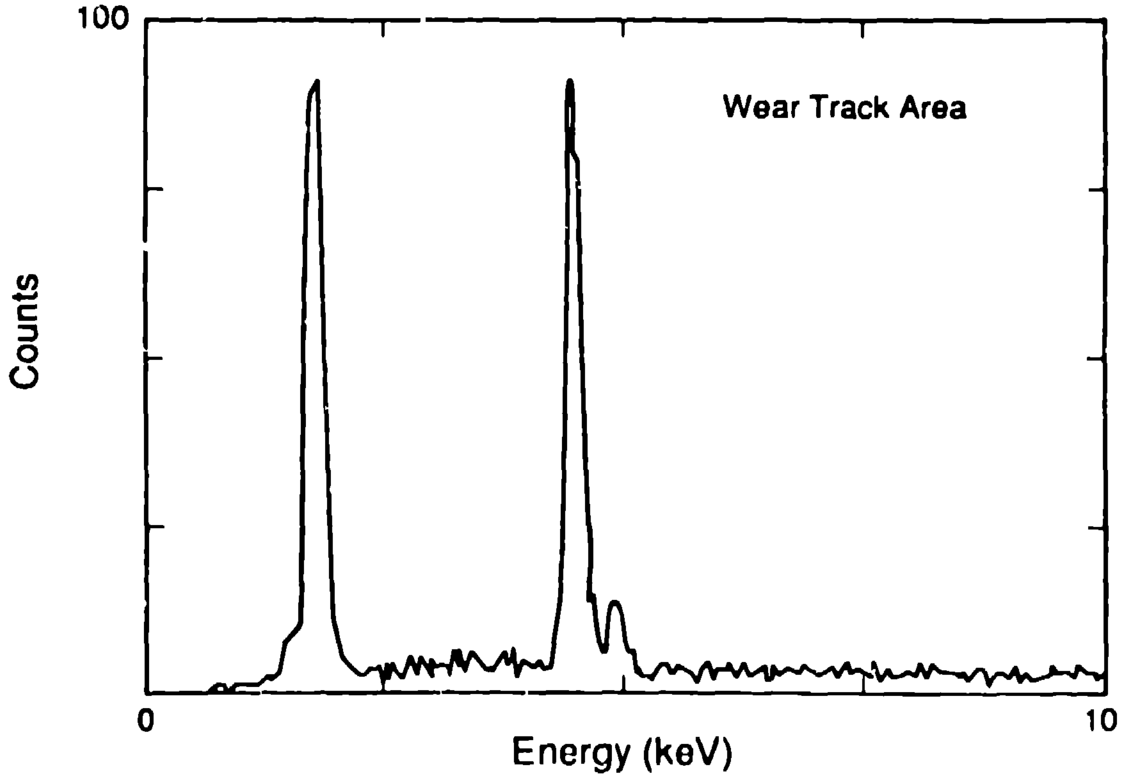

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